UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE OUTLET WORKS BOYSEN DAM MISSOURI RIVER BASIN PROJECT

Hydraulic Laboratory Report No. Hyd.-283

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

DECEMBER 27, 1950

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Laboratory Report No. Hyd-283
Hydraulic Laboratory
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Reviewed by: A. J. Peterka

Subject: Hydraulic model studies of the outlet works--Boysen Dam--Missouri River Basin Project

SUMMARY

The model studies presented in this report were made to develop a low cost stilling basin for the Boysen Dam outlet works which would give satisfactory performance for all discharges. The basin was designed to provide energy dissipation with either one or two of the 48-inch hollow-jet valves operating. Maximum flow for one valve was 660 second-feet and 1,320 second-feet for two valves with a total head of 103.25 feet. The model was built to a scale of 1:16, Figure 5. Starting with a conventional hydraulic-jump-type stilling basin, tests were made on different designs until a basin was developed which gave satisfactory energy dissipation for all operating conditions. The recommended basin did not employ a true hydraulic jump for the stilling action.

Tests on the preliminary design which used the hydraulic jump as an energy dissipator, Figure 6, showed that the stilling basin was too short to contain the jump with either one or two valves operating at maximum discharge. Even though the valves were tilted downward 15° in this design, the water surface in the river channel was rough with high surface velocities, Figure 7. Excessive erosion of the model movable bed also indicated the stilling action was not satisfactory.

A second series of tests was made using deflector hoods, which consisted of curved plates, placed to deflect the flow downward onto the floor of the stilling basin. Five hood designs were tested varying in curvature and length, Figures 8 and 11. Except for the center dividing wall, they were similar to the one used on the Enders Dam outlet works, under investigation at the time of the Boysen studies, and reported in Hydraulic Laboratory Report No. Hyd-252. The deflectors had the effect of increasing the vertical angle of tilt of the valves beyond 15°. The tests showed that variations in deflector curvature or length had only a minor effect on the basin performance. Scour was not serious, but surface velocities in the river channel were high, and undesirable wave action occurred. The optimum performance of the stilling basin using deflectors was considered only fair, probably because refinements in the various arrangements were not fully investigated. The presence of a center dividing wall in the Boysen outlet works also adversely affected the performance of the basin.

In the final series of tests the deflectors were removed and the valves were tilted downward at an angle of 24° to direct the jets under the water surface. The action in the basin was similar to that obtained when using the deflectors until converging walls were added to the upstream end of the stilling basin as shown in Figure 14. The walls compressed the hollow jet between them and induced small-grain turbulence throughout the entire basin volume. The small-grain turbulence, contrasted with the often observed large-grain turbulence or roller action type of energy dissipation, resulted in excellent energy dissipation and very good velocity distribution at the downstream end of the basin. Flow in the river channel was smooth and scour was slight. Operation was satisfactory for all conditions with the performance improving with a decrease from maximum head or discharge. From the appearance of the flow through the glass side of the model stilling basin, it was concluded that the stilling action was not that of a true hydraulic jump, so the term modified hydraulic jump is used to describe the action in the basin.

INTRODUCTION

Boysen Dam is located on the Big Horn River in central Wyoming, 16 miles south of the town of Thermopolis, Figure 1. It will serve the multiple purpose of flood control, irrigation storage, and power development. The dam of compacted earth fill is 1,100 feet long at the crest and rises 150 feet above the bed of the river, Figure 2. An open channel spillway is located at the right abutment, Figures 2 and 3, for the purpose of passing flood discharges. Control of the spillway is provided by two 30- by 25-foot radial gates.

The powerhouse on the right bank downstream from the dam contains two 7,500-kva generator and turbine units. Because of the economy of combining structures, the outlet works is located in the powerhouse, Figure 4. It consists of two 48-inch hollow-jet valves which discharge into a concrete stilling basin located adjacent to the turbine draft tubes. The stilling basin is divided into two sections, one for each valve, by a wall which extends from the valves to the end of the basin and which also serves as a support for the powerhouse. Water is supplied to one valve by a 57-inch pressure conduit which is a branch from one of the penstocks. The other valve is connected by a 66-inch line to the reservoir directly.

The function of the outlet works stilling basin is to dissipate the energy contained in the high-velocity jets leaving the valves and thus prevent undermining of the structure and destruction of the river channel downstream from the dam. The purpose of the model studies was to develop a moderate cost stilling basin that would provide this energy dissipation. Design of the basin was restricted by considerations of economy and adaptation to local conditions.

THE 1:16 SCALE MODEL

The model of the outlet works was built to a scale of 1:16; Figure 5. By using this scale, 3-inch hollow-jet valves, which were in stock in the laboratory, could be used to represent the 48-inch valves of the prototype. The reservoir upstream from the dam was represented in the model by a 3- by 3-foot metal-lined wooden head box 10 feet high with the top open to the atmosphere. Each model valve was connected to the head box by a section of 3-inch pipe. An 8-inch pipe leading from the laboratory pumps supplied water to the head box. A rock baffle in the head box served to smooth out the flow of water before it entered the 3-inch conduits.

Other features reproduced in the model were the stilling basin and a section of the river channel 150 feet long (prototype) downstream from the basin. These were built inside a wooden tail box lined with sheet metal. In the construction of the stilling basin, the sides of the tail box served as the basin training walls. Concrete was used for the basin floor and the center dividing wall was made of wood. The river channel was molded in sand of which all passed a No. 8 sieve and 90 percent was retained on a No. 50 sieve.

Model discharges were measured by Venturi and orifice meters in the supply lines. Water-surface elevations in the head box were determined visually from a scale on an open-water manometer. Tail-water elevations were measured with a point gage located in the tail box downstream from the stilling basin. After tests on the preliminary design, the tail box was rebuilt and a glass panel was installed in the side of the box which formed the right training wall of the stilling basin.

THE INVESTIGATION

Test procedure consisted of evaluating the effectiveness of the various basins from the operation of the model with both one and two valves open at various discharges up to 660 second-feet through each valve giving a total flow of 1,320 second-feet. For this discharge, the reservoir was at elevation 4725 and the tail water was at elevation 4616, as shown by the tail-water curve in Figure 3. Since the efficiency of each basin was reflected in the wave heights and erosion depths which occurred at the end of the basin, these were recorded and used to determine the relative value of each basin tested. Appearance of the flow as seen through the glass panel was also used to help evaluate the basin performance. In addition to records of wave heights, discharge, and similar data, photographs were taken of the basin in operation and the scour resulting from running the model for 1 hour at maximum discharge.

When operating the model, the proper jet velocity and consequent head on the valve for any discharge was obtained by using a valve opening that would produce a pressure head one diameter upstream from the hollow-jet valves corresponding to that calculated for the prototype. This was necessary since the length of the pipes from the model reservoir to the valve was a minimum having no relationship to the prototype length. Consequently, the water-surface elevation in the head box did not represent the prototype reservoir elevation to scale.

Tests on Stilling Basin

Study No. 1, preliminary design. The preliminary stilling basin, Figure 6, had the valves tilted downward 15° to shorten the jet trajectory and to direct the jets under the tail-water surface. The upstream end of the basin floor conformed to the jet trajectory and the remaining downstream section was horizontal to provide for the formation of an hydraulic jump. Operation of the right valve at 660 second-feet and of both valves at a total of 1,320 second-feet is shown in Figures 7, A and B, respectively. The jump occurred on the horizontal floor of the basin, but the turbulence extended downstream into the river channel indicating the basin was short. In the river channel, strong surface velocities occurred along with a rough water surface due to the surging action of the jump. Scour, though not recorded, was sufficiently deep to be considered unsatisfactory. Satisfactory operation could probably have been obtained by lengthening the basin, but such a solution was considered too costly, and it would also require building the basin across a fault. A more desirable method was to increase the effectiveness of the existing basin.

Study No. 2, deflector studies. It was decided in the second series of tests to investigate the use of deflector hoods in an effort to further shorten the jet trajectory, thus allowing use of more of the overall length of the basin for dissipating energy. The deflector hoods consisted of inclined plates, either straight or curved, placed in the path of the jet to deflect it downward as it entered the basin. This shortened the horizontal length of the trajectory by 30 feet, so the stilling basin was modified by using a steeper slope at the upstream end of the basin and a longer horizontal floor as shown in Figure 8. The center wall was necessary in the preliminary basin to obtain a satisfactory jump with one valve operating. With the deflectors in use, it was believed the full-length wall would not be necessary as in the hydraulic jump basin; consequently, it was reduced in length by 74.4 feet which allowed the wall to extend just beyond the deflectors. A glass panel was installed in the right side wall of the basin to observe flow under the deflector hoods.

Using this stilling basin, the three deflector hoods, Nos. 1, 2, and 3, shown in Figure 8, were tested. For each deflector, the model was operated with one valve discharging 660 second-feet and with both valves discharging a total of 1,320 second-feet. Flow in the basin as seen through the glass panel is shown in Figures 9A, B, and C. Appearance of the water surface in the stilling basin and river channel for Deflector Hoods Nos. 1, 2, and 3 is shown in Figures 10A, B, and C. In all tests, operation was improved over that for the preliminary design since with a longer usable basin the turbulence was confined to the stilling basin and wave heights were reduced in the river channel. The concave deflectors, Nos. 2 and 3, gave better results than the convex deflector, No. 1, since the jets were deflected downward at a steeper angle with better dispersion of the jet. Piezometers were installed in one bay along the centerline of Deflector No. 2. The pressures recorded for the maximum discharge are shown in Figure 8B. All pressures were above atmospheric with the maximum value of 17 feet of water occurring at Piezometer No. 3.

The results of tests with Deflector Hood No. 3 indicated the length of the basin to be adequate. While energy dissipation in the basin was good, there was a velocity concentration at the water surface as the flow left the stilling basin. Waves in the downstream channel were about 1-1/2 feet high. From observations through the glass wall, it was seen that the surface velocity concentration at the downstream end of the basin was a continuation of the high-velocity current emerging from under the deflector. The current did not disperse throughout the basin but caused a boil and a concentration of velocity on the water surface.

The jets from the valves entrained a considerable quantity of air which it is believed reduced the density of the high-velocity water, causing it to rise rapidly to the surface. Baffle piers placed on the floor downstream from the deflectors to break up the jets did not improve the flow distribution but only helped to direct the jets upward increasing the boil at the water surface.

The stilling basin was modified for Deflector Hoods Nos. 4 and 5, Figure 11. It was believed that greater basin depth would help to disperse the valve jets and reduce the high-velocity surface current. To obtain this increase in depth, the sides of the model, the valve structure, and the downstream topography were raised and a larger glass panel installed for the right training wall. A sloping floor connected the horizontal apron with the river bottom. The center dividing wall was lengthened to that of the preliminary design because the design section decided this length was necessary for support of the powerhouse. The basin and Deflector No. 4 are shown in Figure 11A.

Stilling basin performance using Deflector No. 4 with two valves discharging a total of 1,320 second-feet is shown in Figure 12A and Figure 13A. Action was similar to that obtained with Deflectors Nos. 2 and 3 as a concentration of flow and a boil resulted in high velocity flow at the water surface downstream from the deflector Figure 12A shows the upward flow of air and water in the stilling basin. However it was believed the greater basin depth used with Deflector No. 4 showed an improvement in vertical distribution of the velocity at the downstream end of the basin; so it was decided to make a test with a still greater depth.

For Deflector Hood No. 5, Figure 11B, the basin depth was increased an additional 16 feet, and the length of the deflector was also increased to bring it to within 10 feet of the floor. Figure 12B and Figure 13B show the operation of the stilling basin with a total flow of 1,320 second-feet from the two valves The upward flow downstream from the deflector was even more pronounced than with Deflector No. 4 due to the step in the floor. There was no appreciable change in the surface velocity or the waves in the river channel from Deflector Hood No. 4. In all of the studies using deflectors, sufficient energy dissipation was obtained, but the vertical velocity distribution of the flow leaving the basin was not satisfactory. Surface velocities were high with correspondingly low bottom velocities.

At this time in the investigation the designers found that it would be possible to tilt the valves downward as much as 24°. With this tilt there was less need for a jet deflector and it was decided to continue the stilling basin tests using other means to obtain better performance.

Study No. 3, Basin No. 3. The next tests were made with the stilling basin floor raised, the deflector removed, and the basin modified as shown in Figure 14. The downward tilt of the valves was increased to an angle of 24° to direct the jet under the water surface in the stilling basin. The lowest floor section at elevation 4596 was 1 foot above the preliminary design since previous tests indicated this depth was sufficient to contain the action in the basin. The full-length center wall was also used

With both valves discharging a total of 1,320 second-feet, the performance as seen through the glass panel is shown in Figure 15A and as seen from the surface is shown in Figure 15B. The flow had a characteristic surging action which produced a rough water surface in the river channel, but the turbulence extended throughout a greater basin volume, Figure 15A, than occurred in any of the tests using deflectors. Surface velocity was still higher than desired at the downstream end of the stilling basin, but the action was fully contained in the basin indicating that the general arrangement and over-all length of the basin were adequate.

Erosion resulting from 1 hour of operation at 1,320 second-feet is shown in Figure 16. Greatest depth of scour was about 1/2 foot lower than the elevation of the basin floor, Figure 16, and occurred at the end of the paved floor. In the photograph, the wide band of sand washed off the slope in right foreground is evidence of the action of the waves having a height of 2 feet which occurred in the river channel. Since surface velocities and waves were still objectionable, it was decided to investigate the use of baffle piers or chute blocks as an aid to improving the stilling basin performance.

Experiments with various sizes and arrangements of baffle piers did not improve the stilling action, but made it worse because these devices directed the flow to the surface which resulted in even greater concentration of flow at the water surface. Examination of the operation without baffles, Figure 15A, however, showed a real need for decreasing the concentration of flow near the surface and increasing the flow along the floor.

To improve the basin performance, a vertical wall was installed at the downstream end of the basin, Figure 14. This wall blocked off the upper 6 feet of water surface giving the effect of a gate operating with submerged flow. Performance within the stilling basin was unchanged, but the flow leaving the basin was smooth and well distributed. While the results were satisfactory for a particular discharge, such a wall was undesirable because the variation in tail-water elevation for other discharges would vary the submergence of the wall and thus change its effectiveness.

Study No. 4, recommended design. Tests made with various arrangements of chute blocks indicated that improvement in operation occurred with a block against each wall at the toe of the slope of the basin in Figure 17. The jet flowing between the blocks was directed along the floor but the tops of the blocks were horizontal and some water was deflected along the top surfaces. By increasing the height of the blocks until they were above the water surface, this flow was eliminated and better performance was obtained. Since the square corners at the upstream end of the blocks obstructed flow from the valves, they were tapered into the wall giving a wedge shape to the blocks in plan view. With this design, very good performance was obtained, but further study was made on the width of opening between the blocks, or more appropriately now, converging walls. Variation in the opening at the downstream end of the walls gave best results with a width of 6 feet. It was also discovered that still better performance resulted when the downstream ends of the walls were moved a distance of 6 feet upstream from the toe of the chute. The improvement resulting from the use of the walls is readily shown by comparing Figure 15A with Figure 18A and also Figure 15B with Figure 19A. Figure 18 shows operation of the recommended basin with one valve open, and Figure 19 shows operation with two valves open at maximum and one-half maximum discharge. Performance was equally good with either one or two valves operating. Maximum wave heights were 1/2 foot in the river channel with this arrangement. The stilling basin was effective for all discharges from the valves. A plausible explanation for the striking improvement resulting with the converging walls installed is that the jet was protected from being torn apart by induced side eddies and compressed into a smaller area giving it more penetrating power. The jet thus continued along the floor a greater distance and fine-grain turbulence was developed, giving a uniform velocity distribution in the basin with a flat water surface having very little wave action. Operation at maximum flow was acceptable even after lowering the tail water 5 feet below normal.

Pressures on the sloping and horizontal floors of the stilling basin were all above atmospheric, Figure 17. Values shown in the table were measured above the piezometer openings. Pressures on the downstream end of the converging walls were also above atmospheric indicating that the abrupt increase in width, at this point, did not cause low pressures. For the discharge of 1,320 second-feet, velocity measurements were made at the downstream end of the stilling basin. Velocity contours are shown in Figure 20. They show the velocity increasing toward the surface, which is a desirable distribution, since lower bottom velocities will cause less erosion. At the same time, the surface velocity is not high enough to cause harmful currents.

Scour was recorded after 1-hour operation at a total discharge of 1,320 second-feet without an end sill, Figure 21A, and with an end sill, Figure 21B. In both tests, erosion was mild and the action was considered satisfactory. As shown by the photographs, the depth of scour was less with the end sill in place and the streambed did not have the rippled surface which occurred when the end sill was not used. From these results, the end sill with a height of 1 foot was recommended for use in the prototype. Scour was less with the operation of one valve than occurred with both valves operating. Action of the waves which were 1/2 foot high was minor as shown by the appearance of the flow in Figures 18B and 19.

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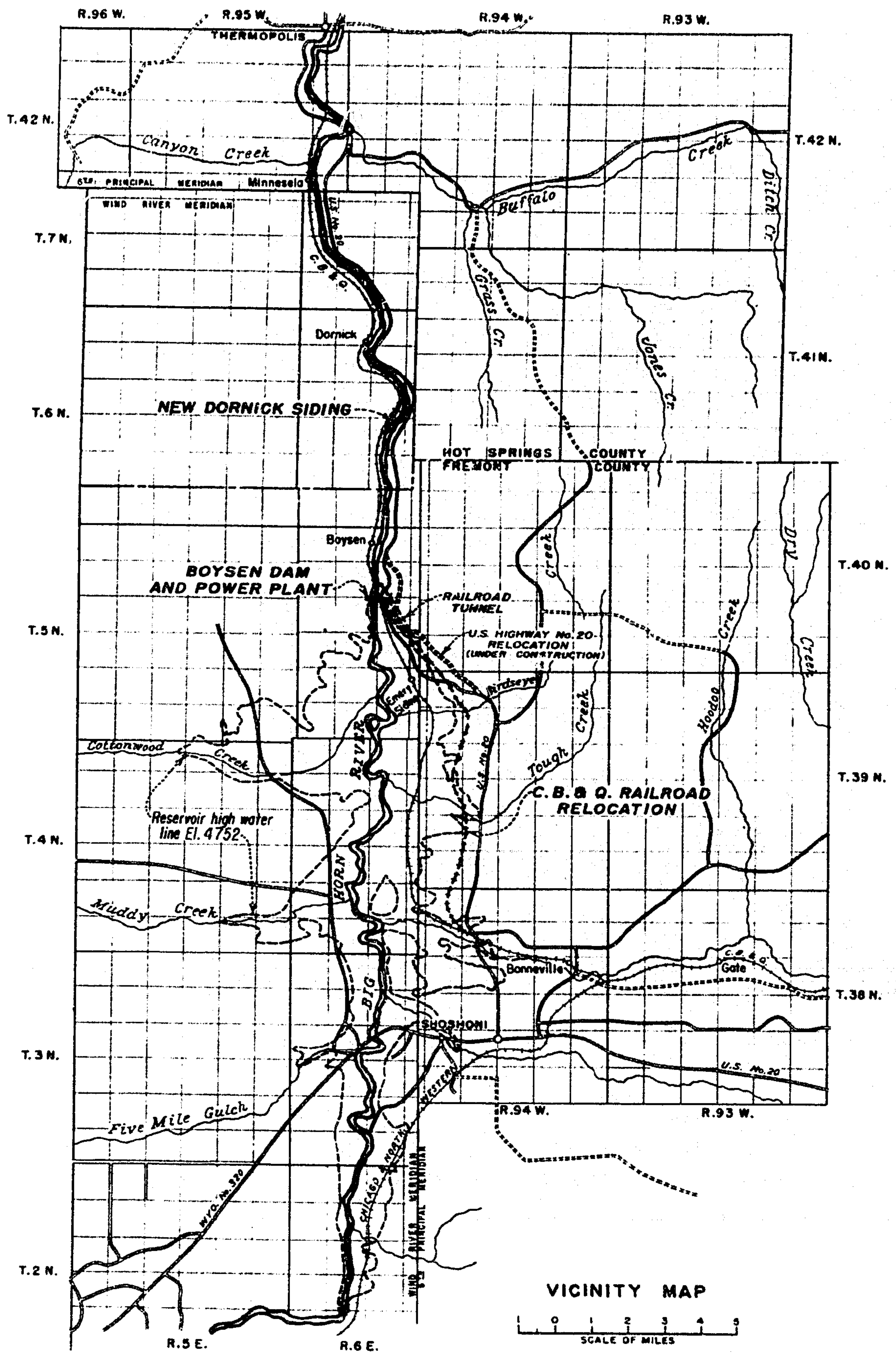
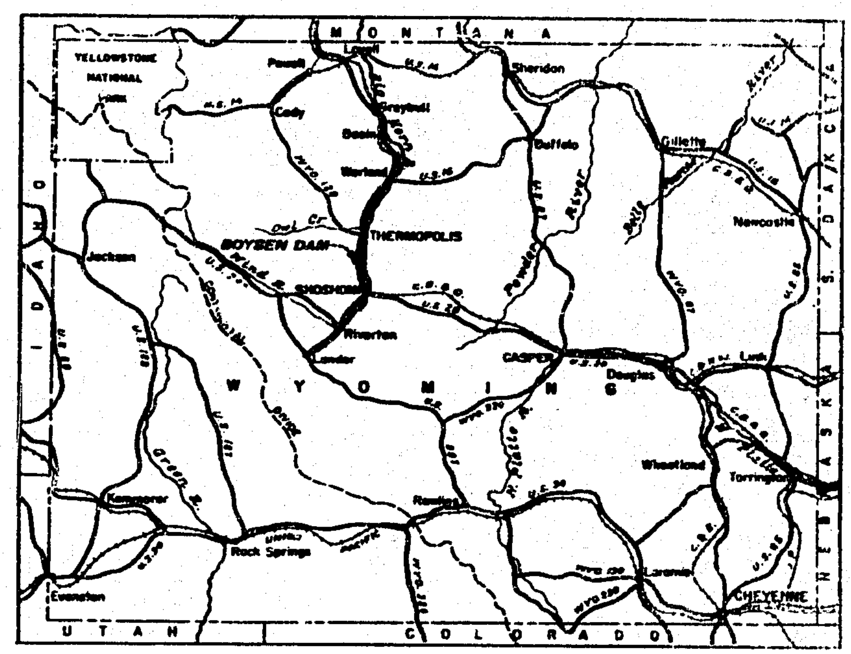
FIGURE I



VICINITY MAP



INDEX MAP

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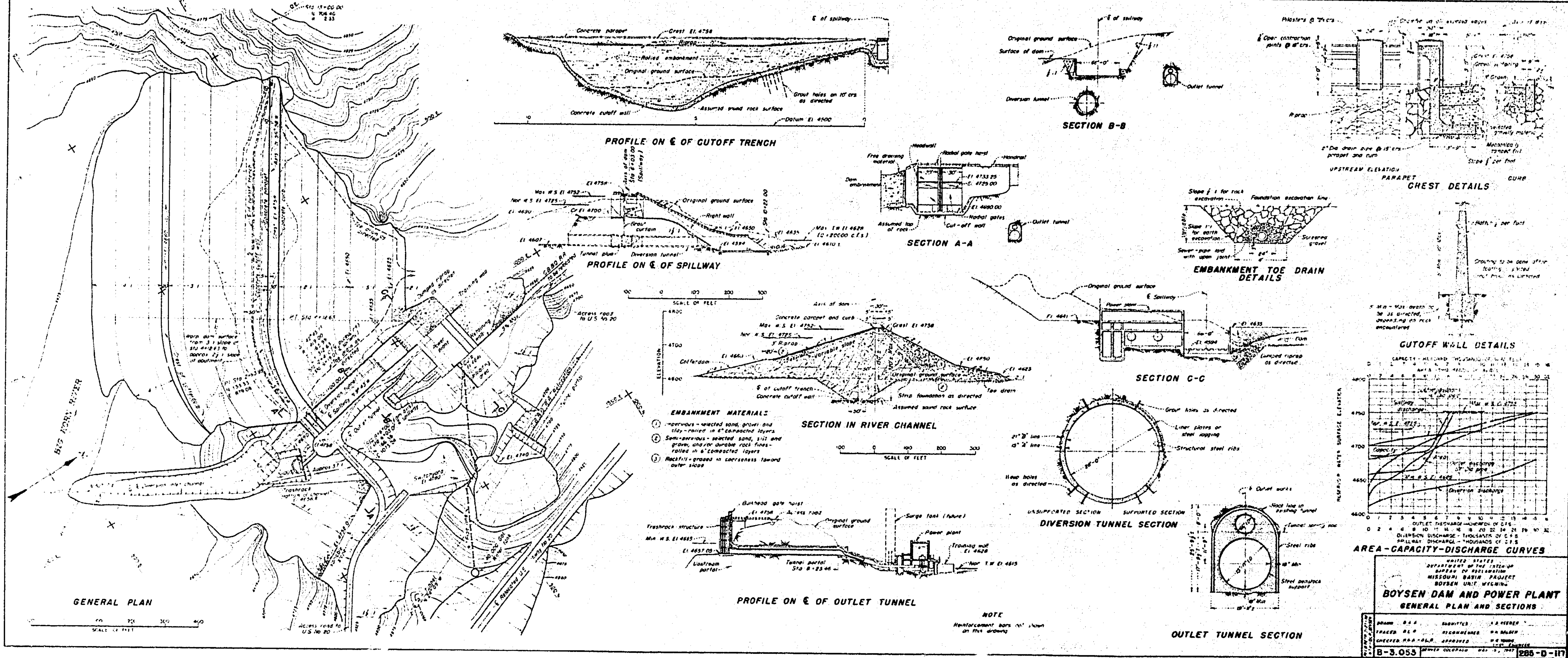
MISSOURI BASIN PROJECT
BOYSEN UNIT-WYOMING

BOYSEN DAM AND POWER PLANT
LOCATION MAP

DRAWN: D.A.A.	SUBMITTED: [signature]
TRACED: C.M.A.	RECOMMENDED: W.H. Nalder
CHECKED: H.G.A. and	APPROVED: Walter R. Young, CHIEF ENGINEER
DENVER, COLORADO, JULY 2, 1946	285-D-110

FIGURE 2


GENERAL PLAN
BIG HORN RIVER
PROFILE ON ℄ OF CUTOFF TRENCH
PROFILE ON ℄ OF SPILLWAY
SECTION B-B
SECTION A-A
CREST DETAILS
UPSTREAM ELEVATION
PARAPET
CURB
EMBANKMENT TOE DRAIN DETAILS
CUTOFF WALL DETAILS
SECTION IN RIVER CHANNEL
EMBANKMENT MATERIALS
SECTION C-C
DIVERSION TUNNEL SECTION
UNSUPPORTED SECTION
SUPPORTED SECTION
AREA-CAPACITY-DISCHARGE CURVES
PROFILE ON ℄ OF OUTLET TUNNEL
OUTLET TUNNEL SECTION
NOTE
Reinforcement bars not shown on this drawing
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MISSOURI BASIN PROJECT
BOYSEN UNIT WYOMING
BOYSEN DAM AND POWER PLANT
GENERAL PLAN AND SECTIONS
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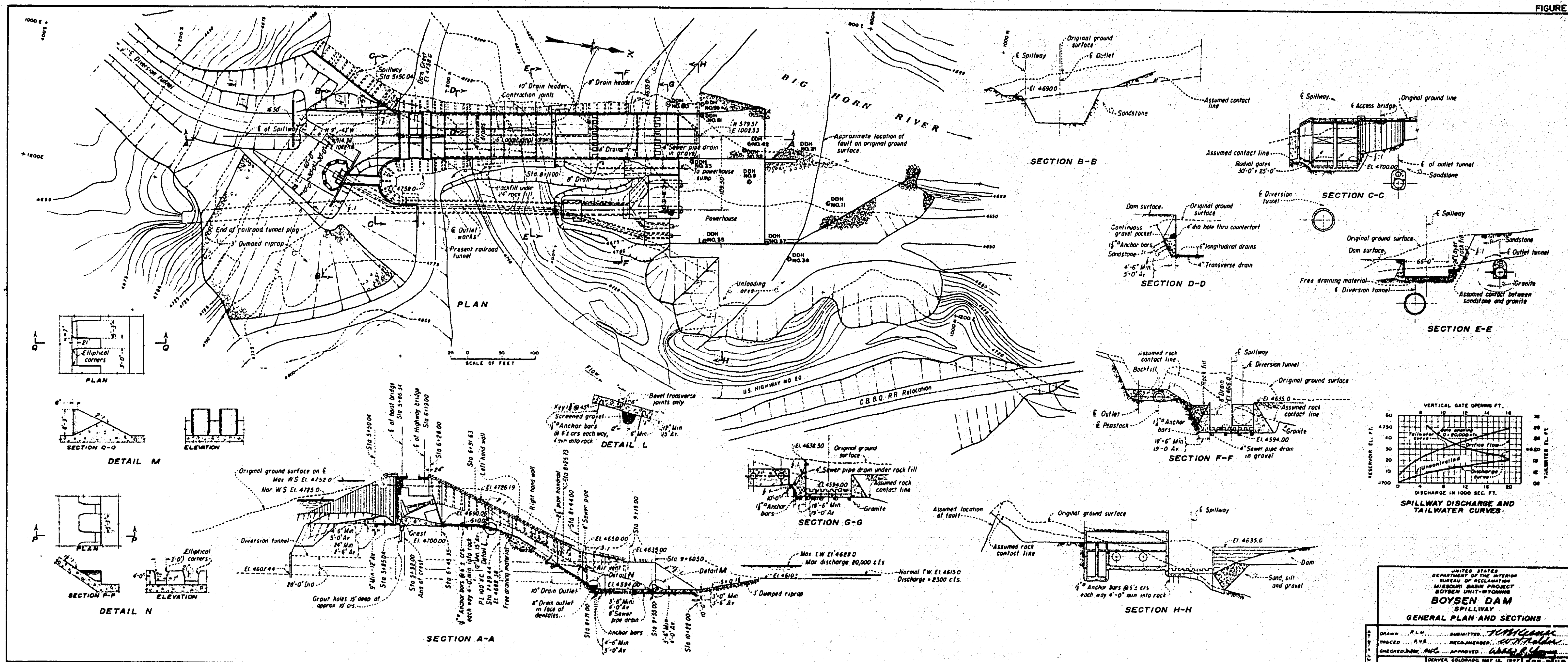
285-D-117

FIGURE 3


BIG HORN RIVER
PLAN
SCALE OF FEET
Powerhouse
US HIGHWAY NO 20
CB&Q RR Relocation
DETAIL M
DETAIL N
DETAIL L
SECTION O-O
SECTION P-P
ELEVATION
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SECTION H-H
Max W.S. El. 4752.0
Nor. W.S. El. 4725.0
Max T.W. El. 4628.0
Max discharge 20,000 c.f.s.
Normal T.W. El. 4615.0
Discharge = 2300 c.f.s.
SPILLWAY DISCHARGE AND TAILWATER CURVES
DISCHARGE IN 1000 SEC. FT.
UNITED STATES
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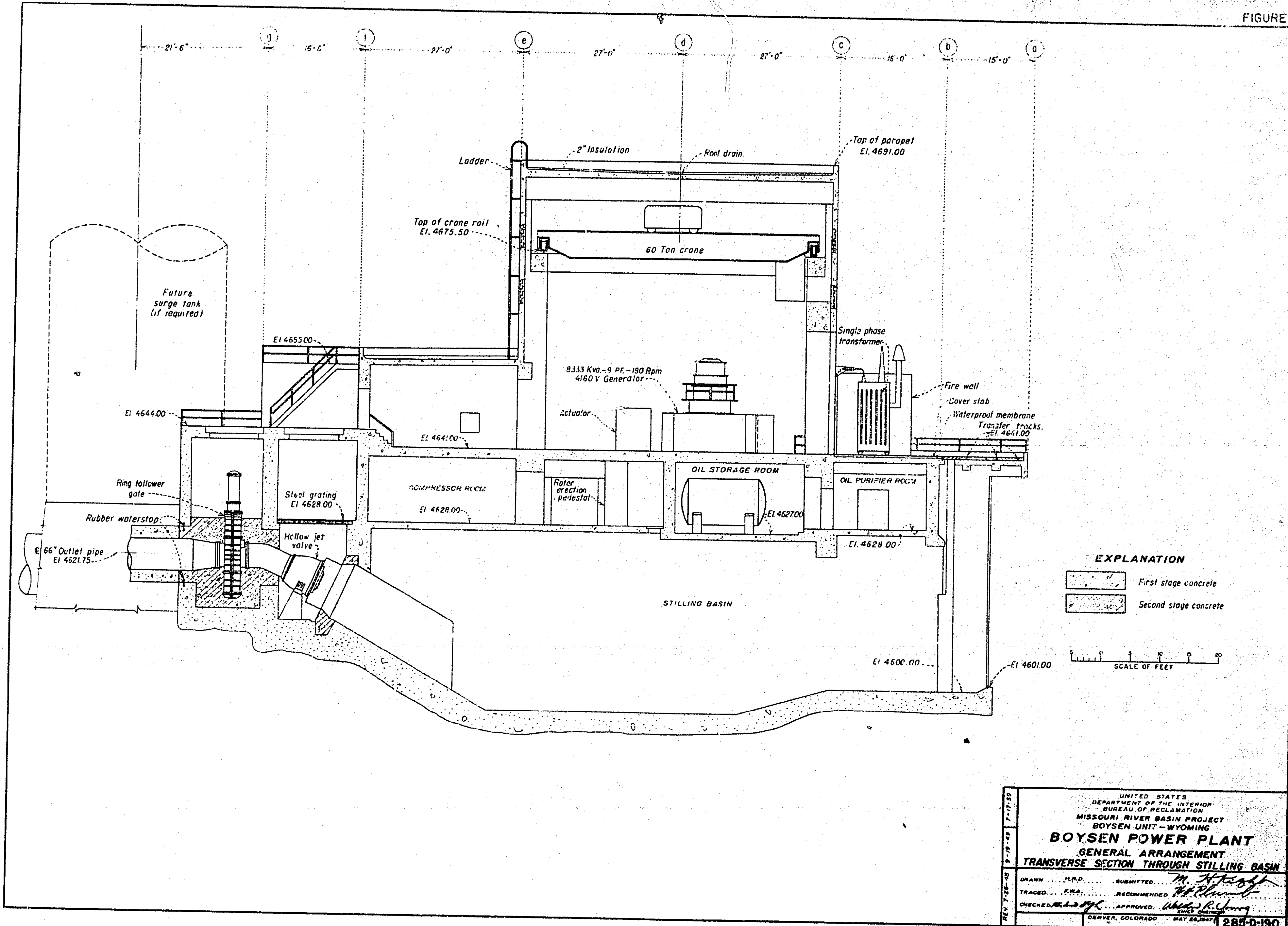
MISSOURI BASIN PROJECT
BOYSEN UNIT-WYOMING
BOYSEN DAM
SPILLWAY
GENERAL PLAN AND SECTIONS
DENVER, COLORADO, MAY 12, 1947

FIGURE 4



g
f
e
d
c
b
a
21'-6"
16'-0"
27'-0"
27'-0"
27'-0"
15'-0"
15'-0"
Ladder
2" Insulation
Roof drain
Top of parapet El. 4691.00
Top of crane rail El. 4675.50
60 Ton crane
Future surge tank (if required)
El. 4655.00
Single phase transformer
8333 Kva.-.9 P.F.-190 Rpm 4160 V Generator
Actuator
Fire wall
Cover slab
Waterproof membrane
Transfer tracks
El. 4641.00
El. 4644.00
El. 4641.00
Ring follower gate
Rubber waterstop
℄ 66" Outlet pipe El. 4621.75
Steel grating El. 4628.00
COMPRESSOR ROOM
El. 4628.00
Rotor erection pedestal
OIL STORAGE ROOM
El. 4627.00
OIL PURIFIER ROOM
El. 4628.00
Hollow jet valve
STILLING BASIN
El. 4600.00
El. 4601.00
EXPLANATION
First stage concrete
Second stage concrete
SCALE OF FEET
UNITED STATES
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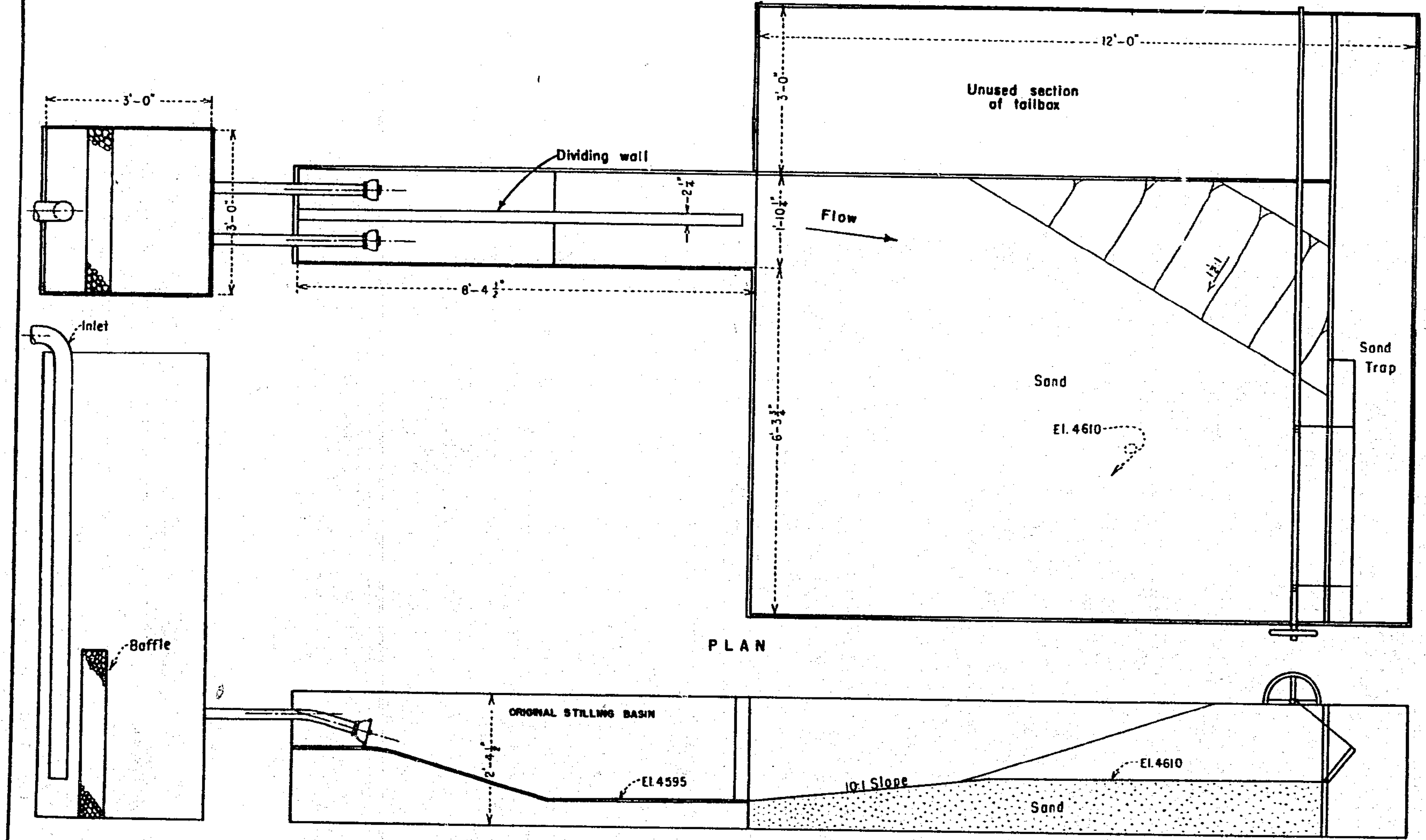
MISSOURI RIVER BASIN PROJECT
BOYSEN UNIT - WYOMING
BOYSEN POWER PLANT
GENERAL ARRANGEMENT
TRANSVERSE SECTION THROUGH STILLING BASIN
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
DENVER, COLORADO
285-D-190

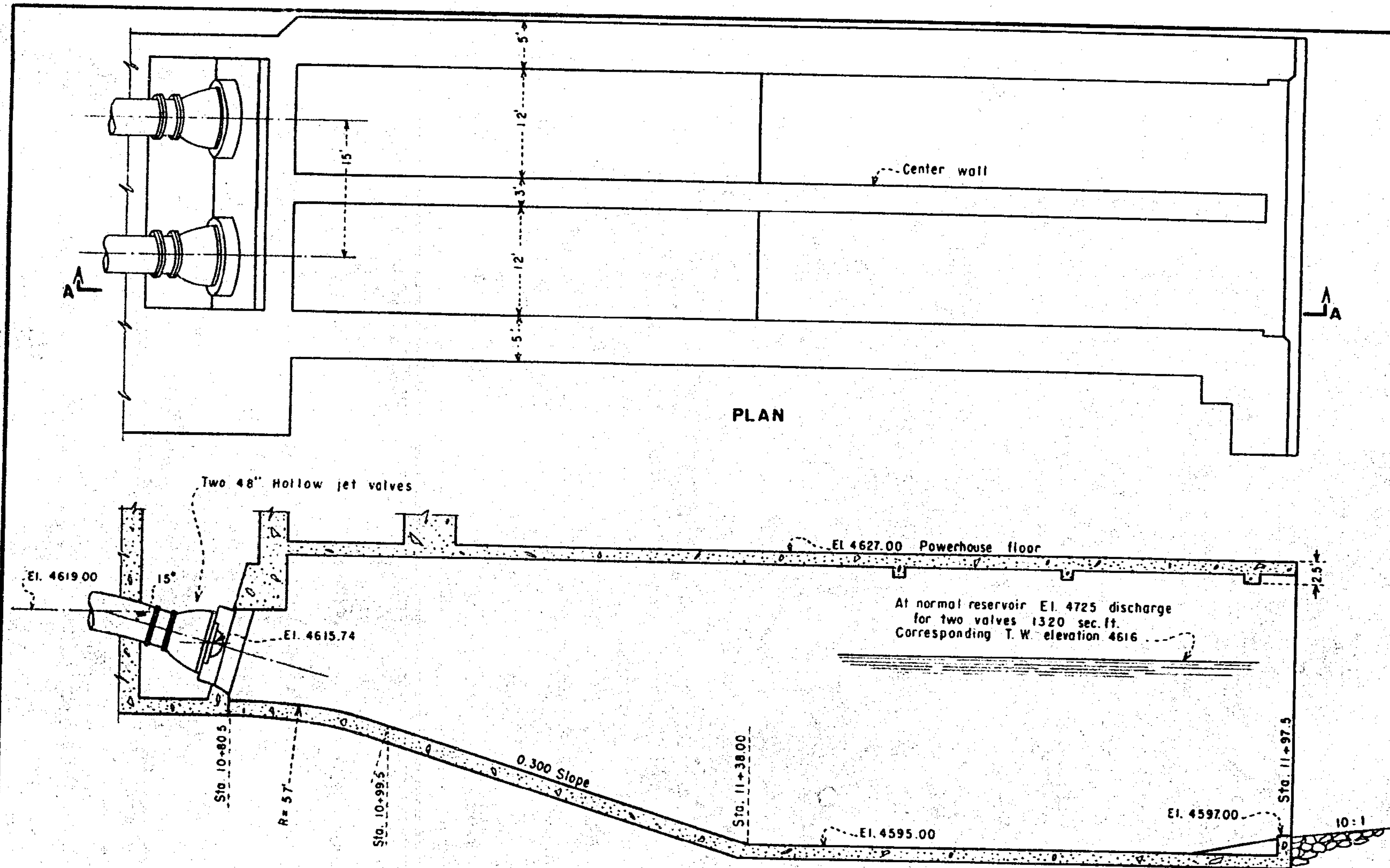


ELEVATION ALONG ℄

1:16 SCALE MODEL LAYOUT

BOYSEN DAM OUTLET WORKS

FIGURE 5



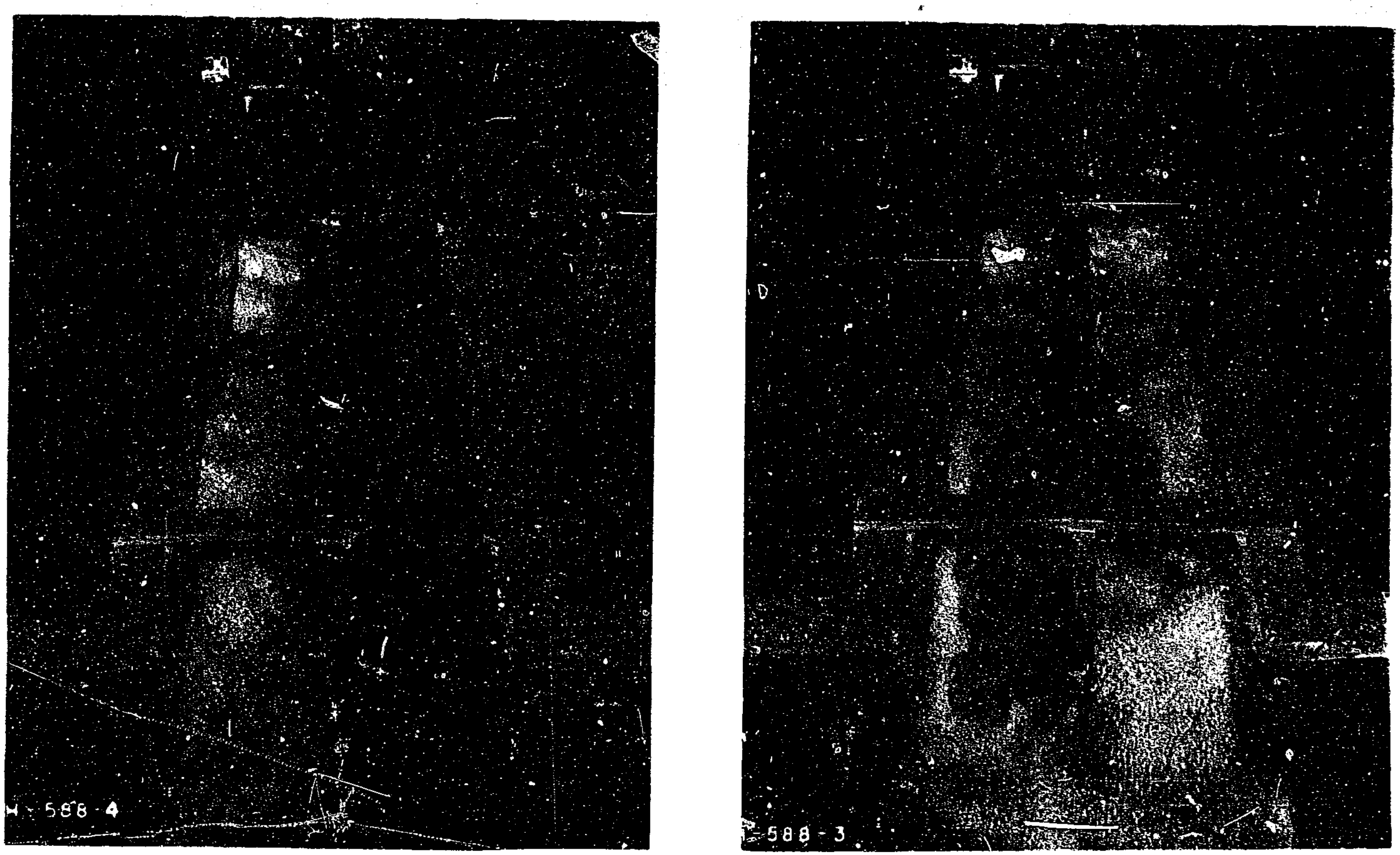
SECTION A-A

ORIGINAL STILLING BASIN

BOYSEN DAM OUTLET WORKS

STUDY NO. 1

FIGURE 6



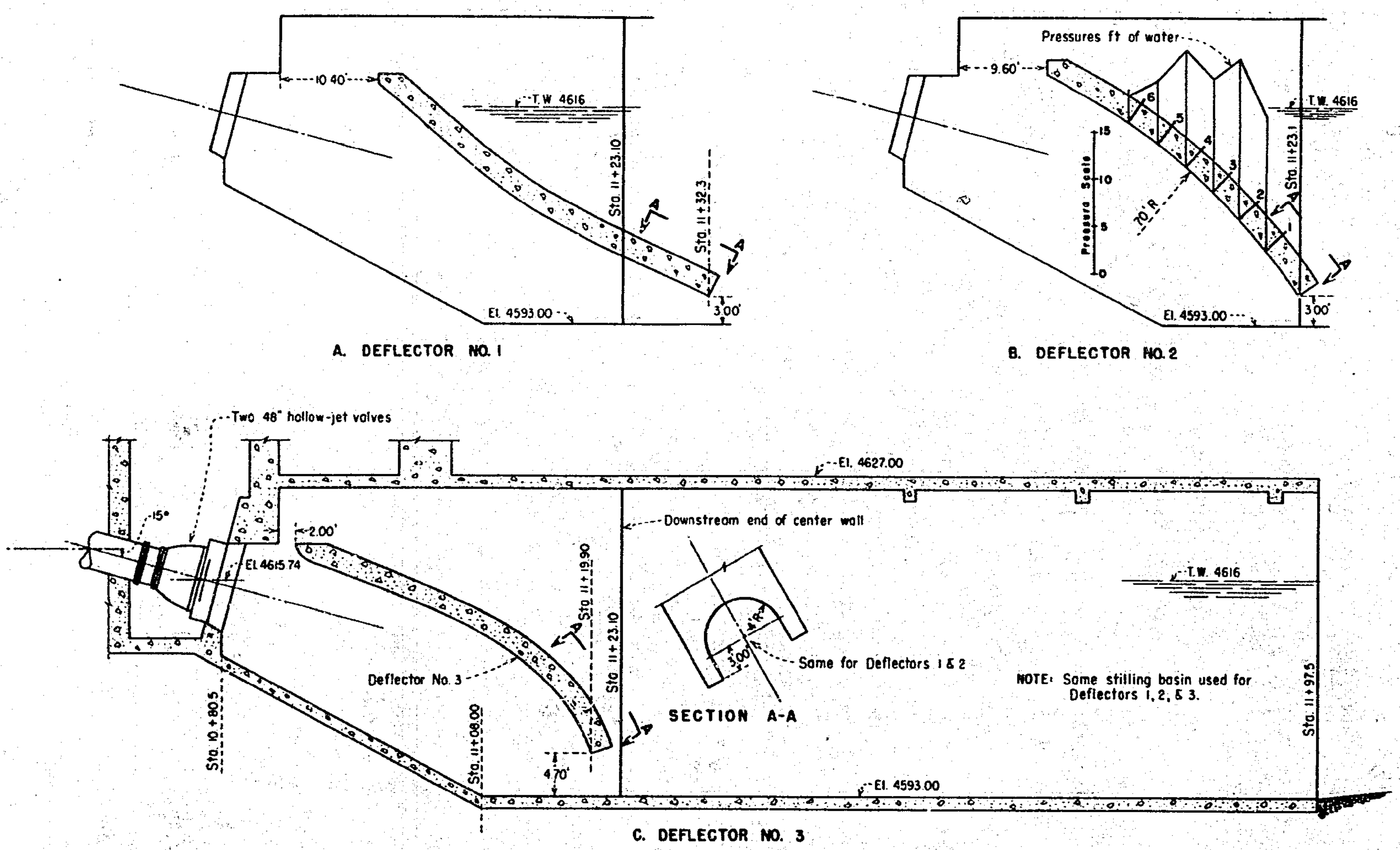
**A. One valve, discharge 660-sec. ft.
Tailwater elev. 4616**

**B. Both valves, discharge 1320 sec. -ft.
Tailwater elev. 4616**

STUDY NO. 1 - ORIGINAL DESIGN

1:16 MODEL BOYSEN OUTLETS

FIGURE 7



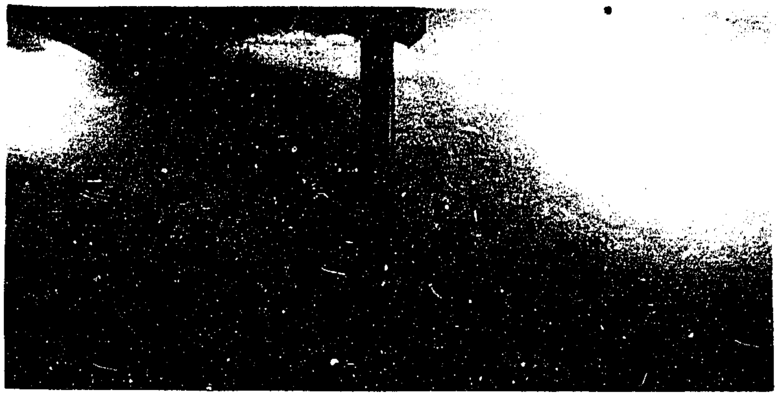
STILLING BASIN NO 2, DEFLECTORS 1, 2, & 3

BOYSEN DAM OUTLET WORKS

STUDY NO. 2

FIGURE 8

A. Deflector No. 1



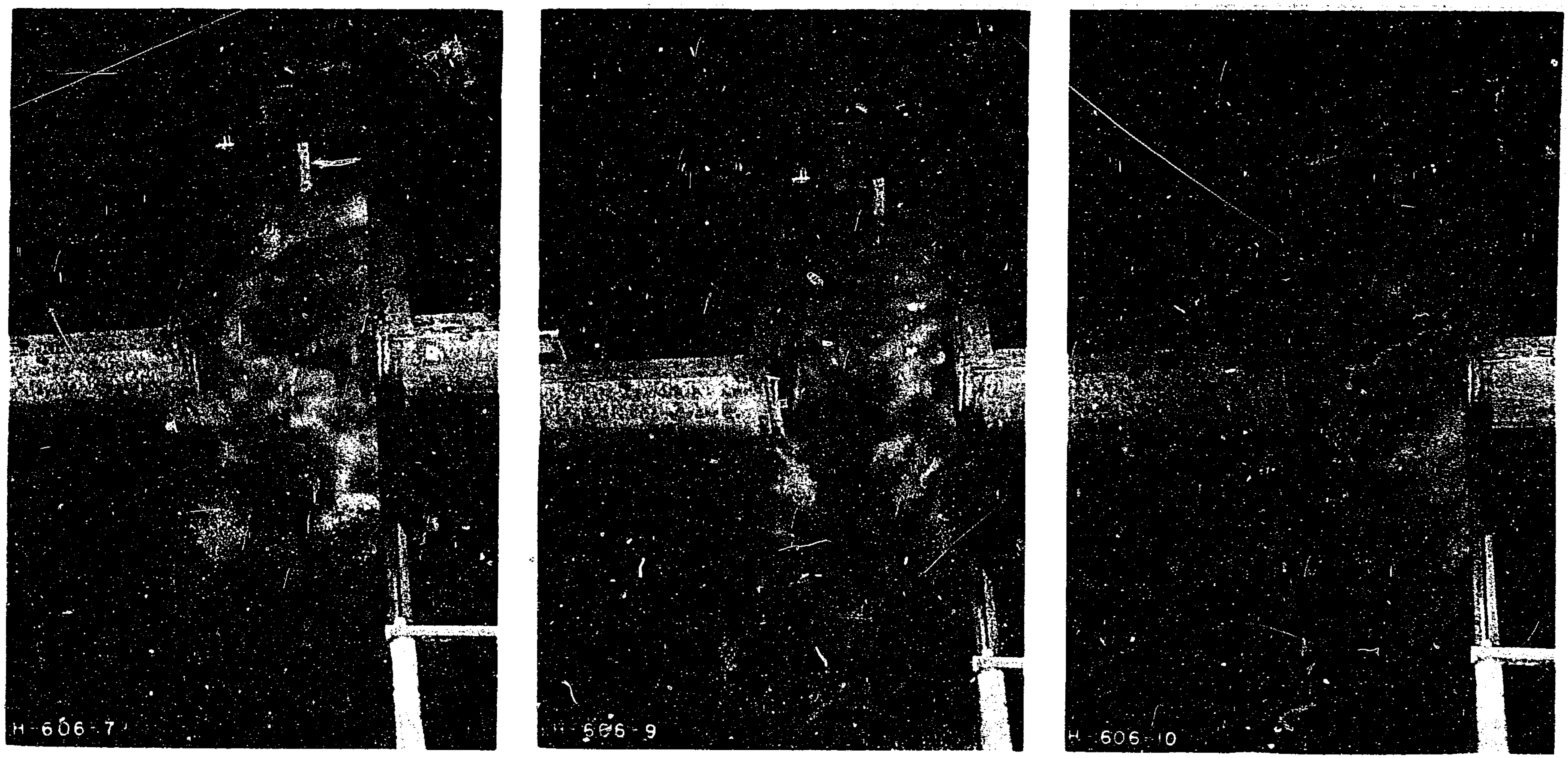
B. Deflector No. 2

C. Deflector No. 3

660 sec. -ft. from each valve

STUDY NO. 2 - DEFLECTOR TESTS

1:16 MODEL BOYSEN OUTLETS



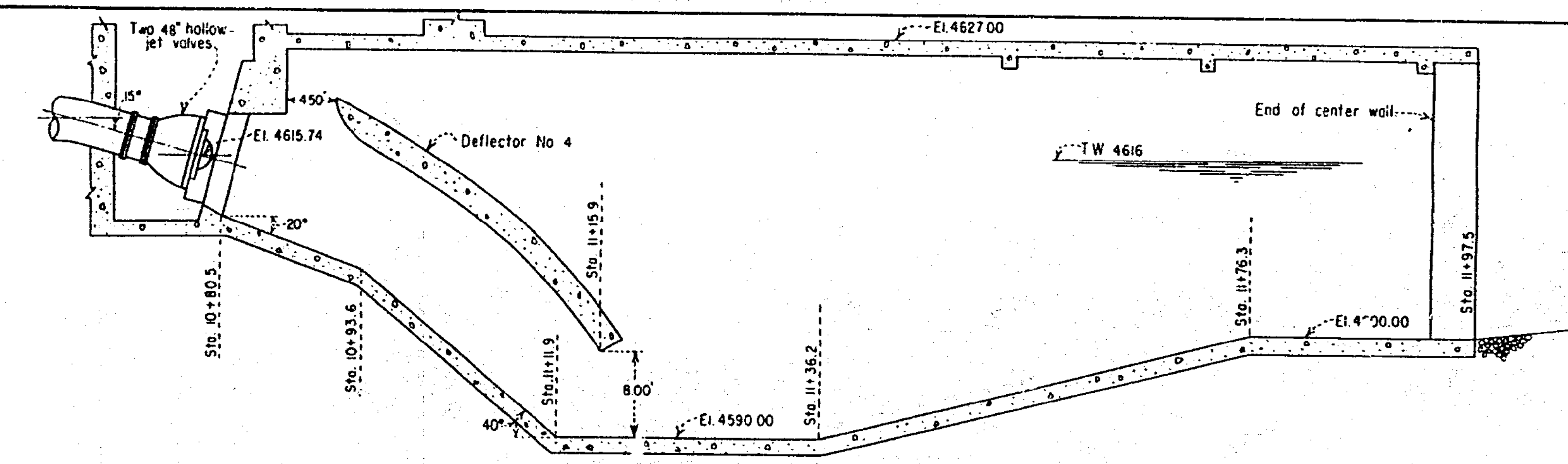
A. Deflector No. 1 B. Deflector No. 2 C. Deflector No. 3

Both valves, discharging 1320 second-feet
Tailwater elevation 4616

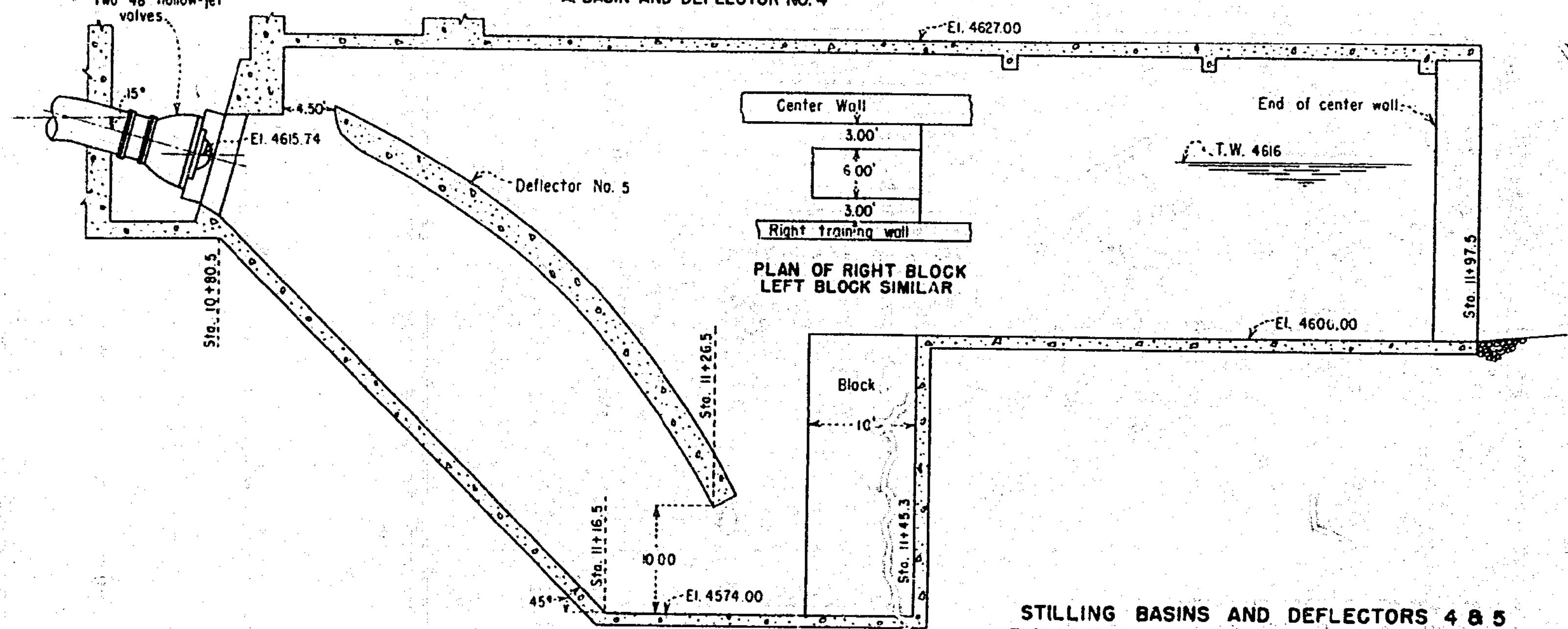
STUDY NO. 2 - DEFLECTOR TESTS

1:16 MODEL BOYSEN OUTLETS

FIGURE 11

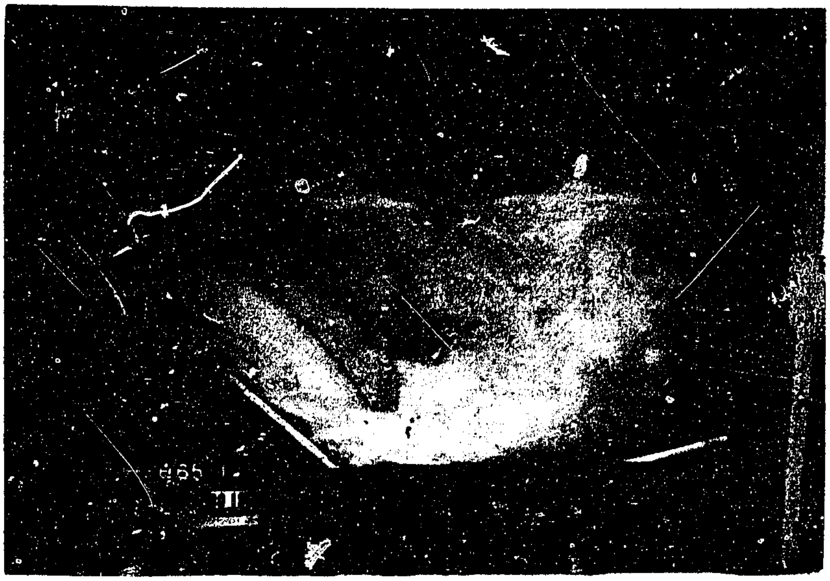


A. BASIN AND DEFLECTOR NO. 4

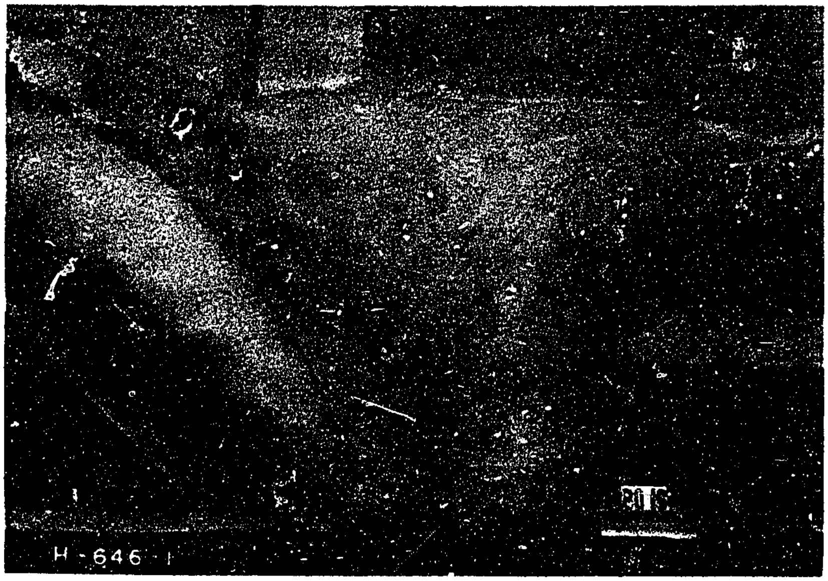


B. BASIN AND DEFLECTOR NO. 5

STILLING BASINS AND DEFLECTORS 4 & 5
BOYSEN DAM OUTLET WORKS
STUDY NO. 2



A. Deflector No. 4

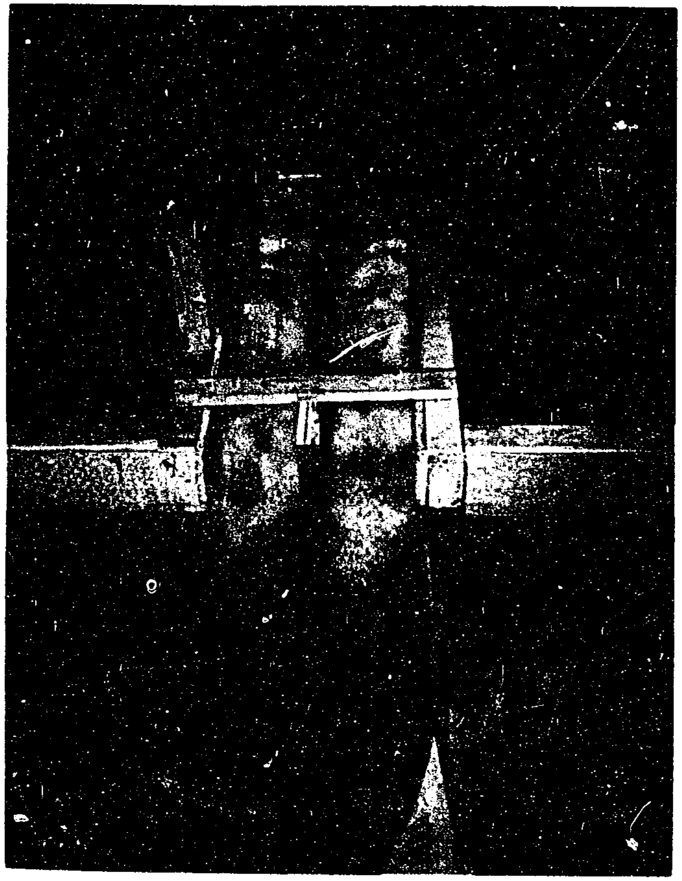


B. Deflector No. 5

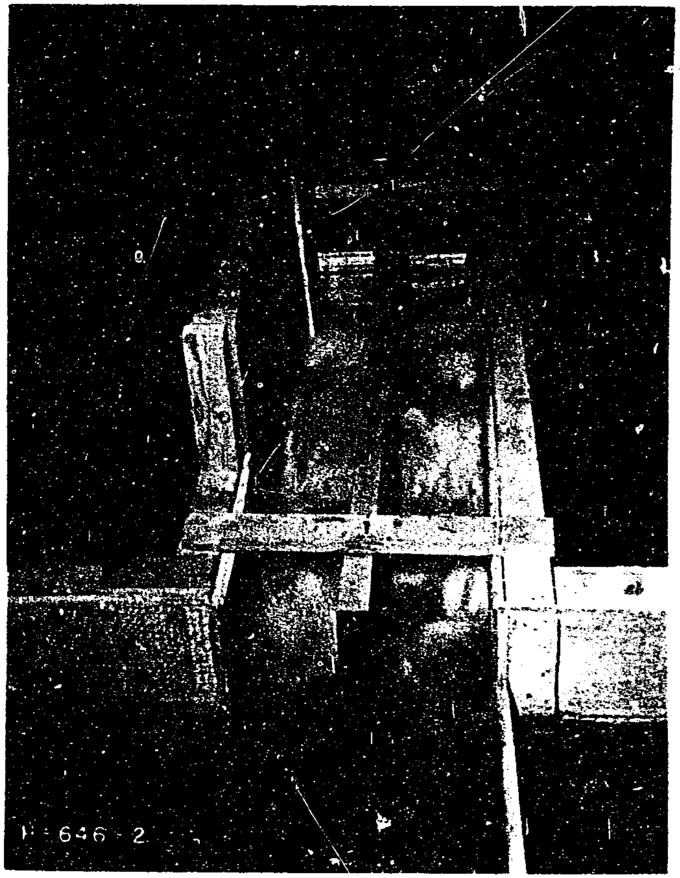
660 sec. -ft. from each valve

STUDY NO. 2 - DEFLECTOR TESTS

1:16 MODEL BOYSEN OUTLETS



A. Deflector No. 4



B. Deflector No. 5

Both valves, discharging 1320 sec.-ft.
Tailwater elevation 4616

STUDY NO. 2 - DEFLECTOR TESTS

1:16 MODEL BOYSEN OUTLETS

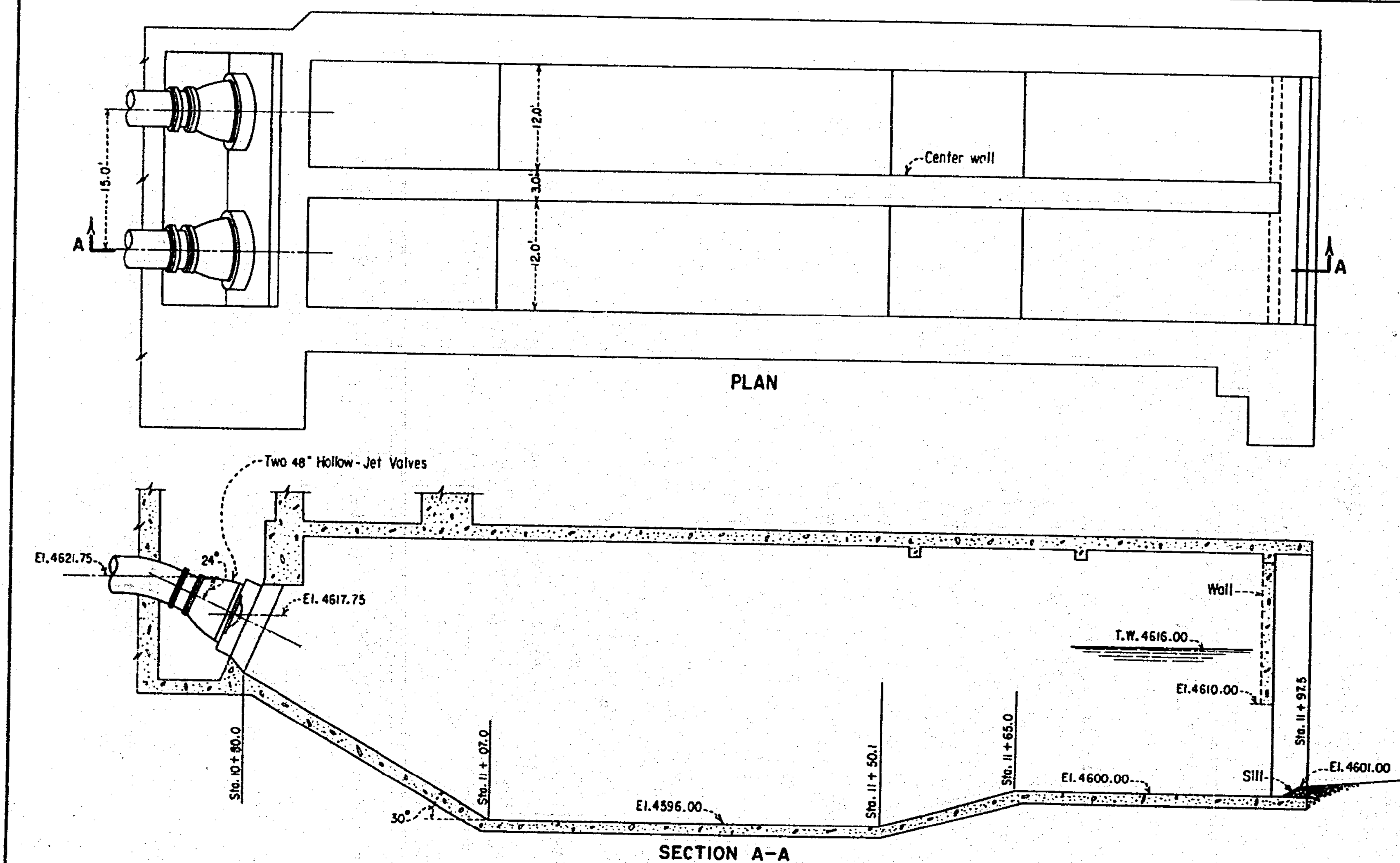
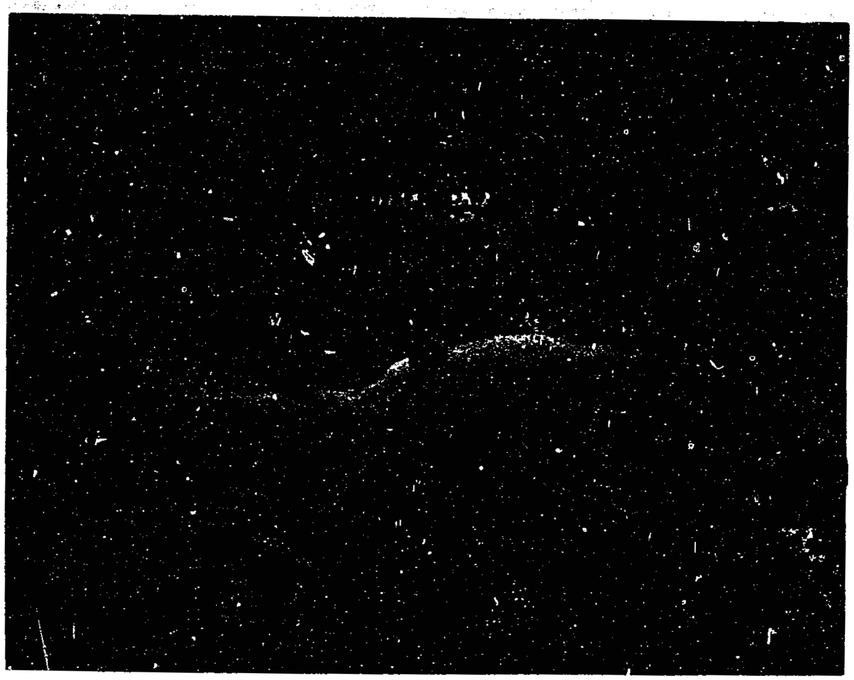


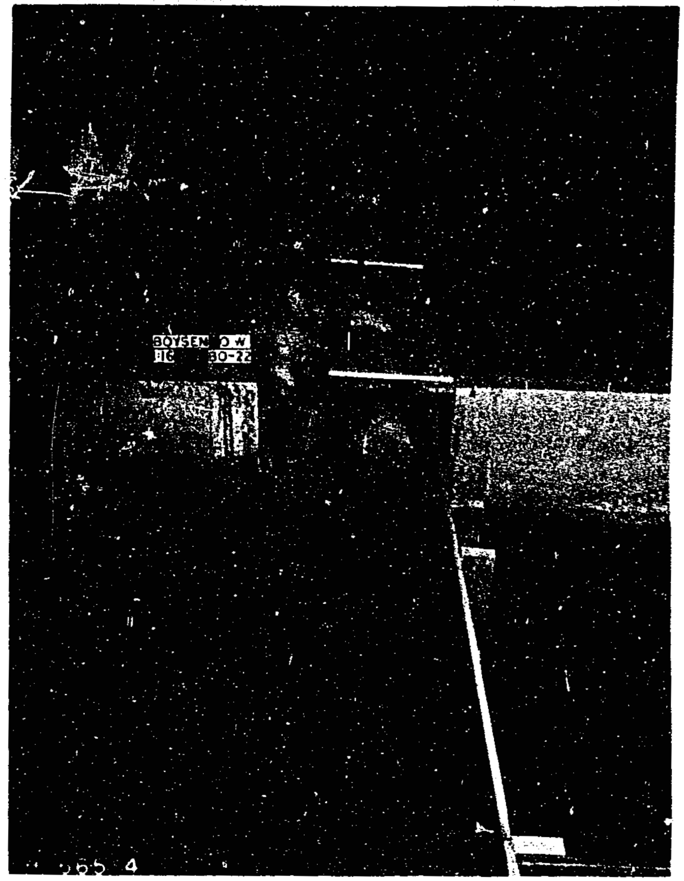
FIGURE 14

BOYSEN DAM OUTLET WORKS
OUTLET WORKS STILLING BASIN
STUDY NO. 3

FIGURE 15



A. Side view



B. Looking upstream

Both valves discharging, 1320 sec. -ft.
Tailwater elevation 4616

STUDY NO. 3

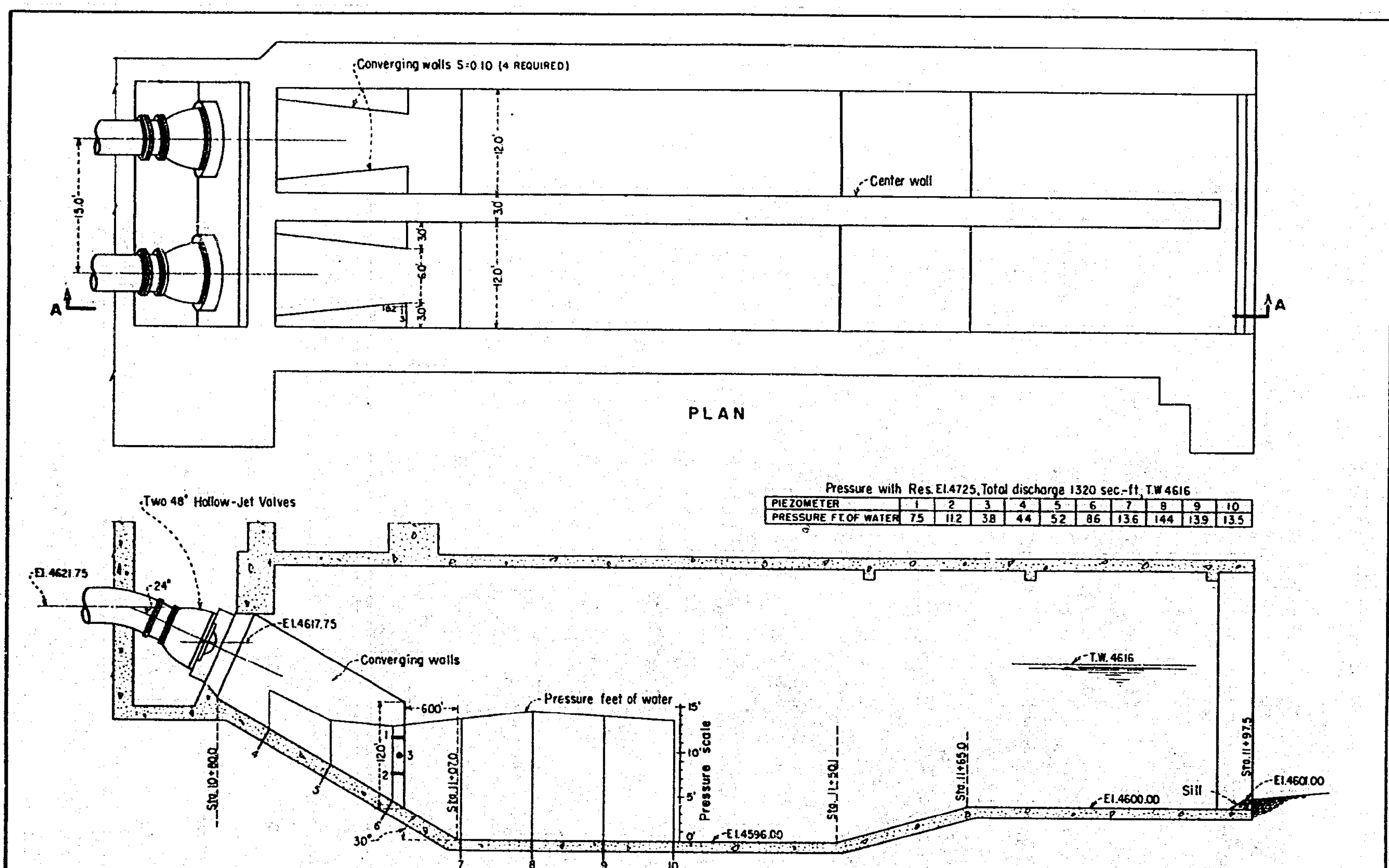
1:16 MODEL BOYSEN OUTLETS

FIGURE 16

Scour after 1 hr. discharge from both valves
of 1320 sec. -ft. tailwater elevation 4616

STUDY NO. 3

1:16 MODEL BOYSEN OUTLETS



Pressure with Res. El. 4725, Total discharge 1320 sec.-ft., T.W. 4616

PIEZOMETER	1	2	3	4	5	6	7	8	9	10
PRESSURE FT. OF WATER	7.5	11.2	3.8	4.4	5.2	8.6	13.6	14.4	13.9	13.5

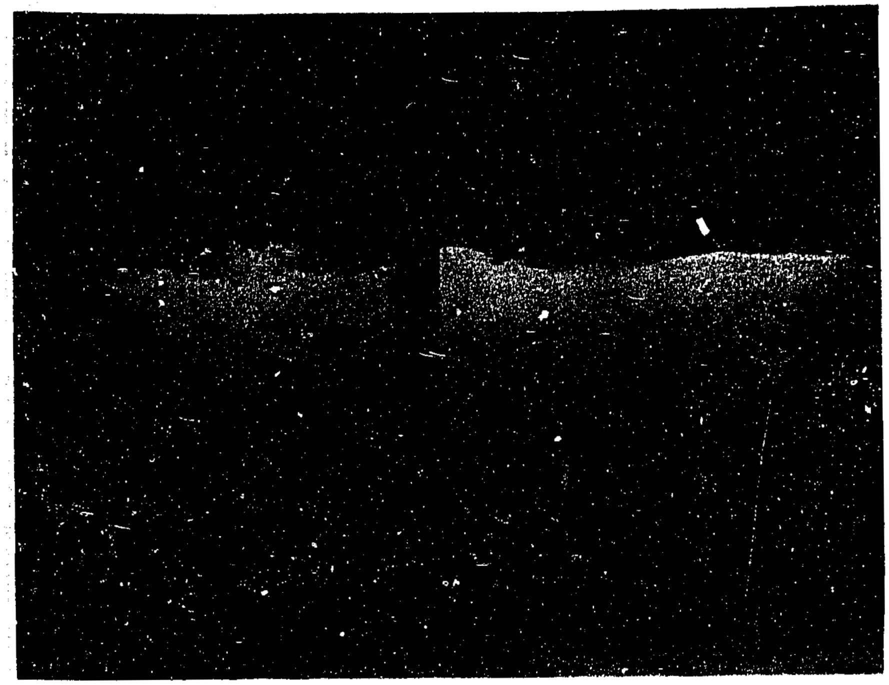
SECTION A-A

STUDY NO. 384

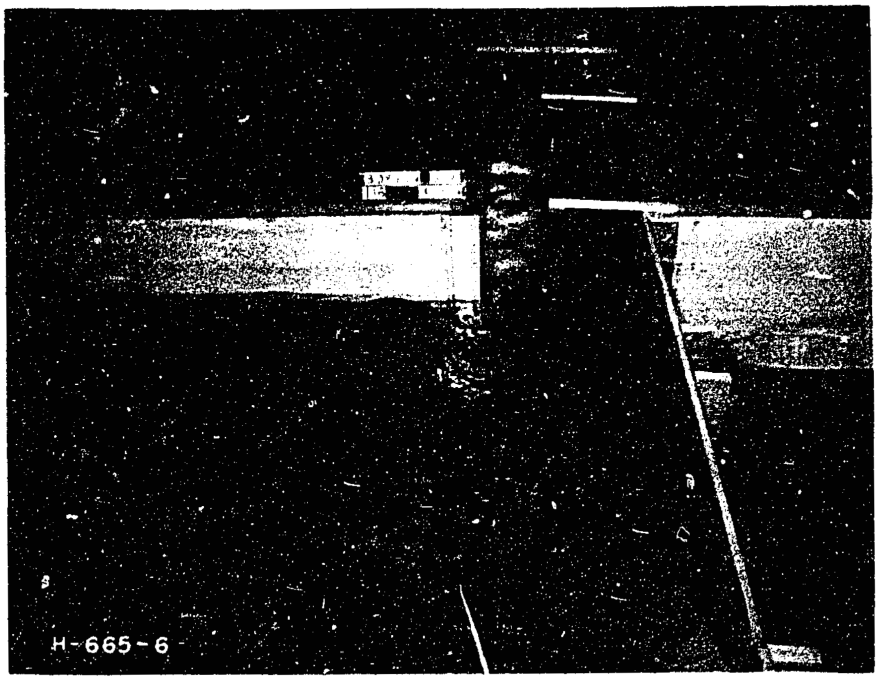
RECOMMENDED STILLING BASIN

BOYSEN DAM OUTLET WORKS

FIGURE 17



A. Two valves discharging 1320 sec. -ft.



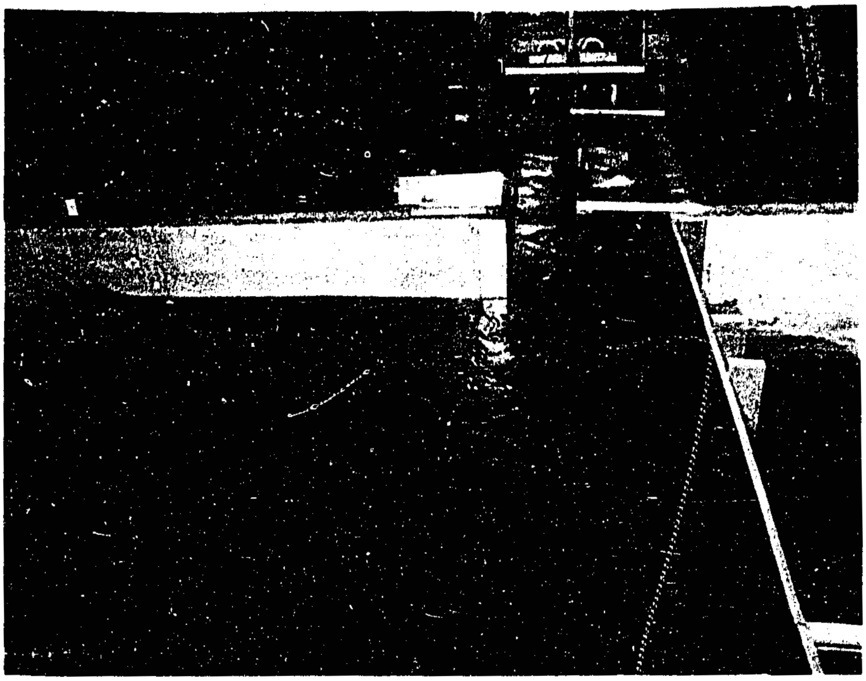
B. One valve discharging 660 sec. -ft.

Tailwater elevation 4616

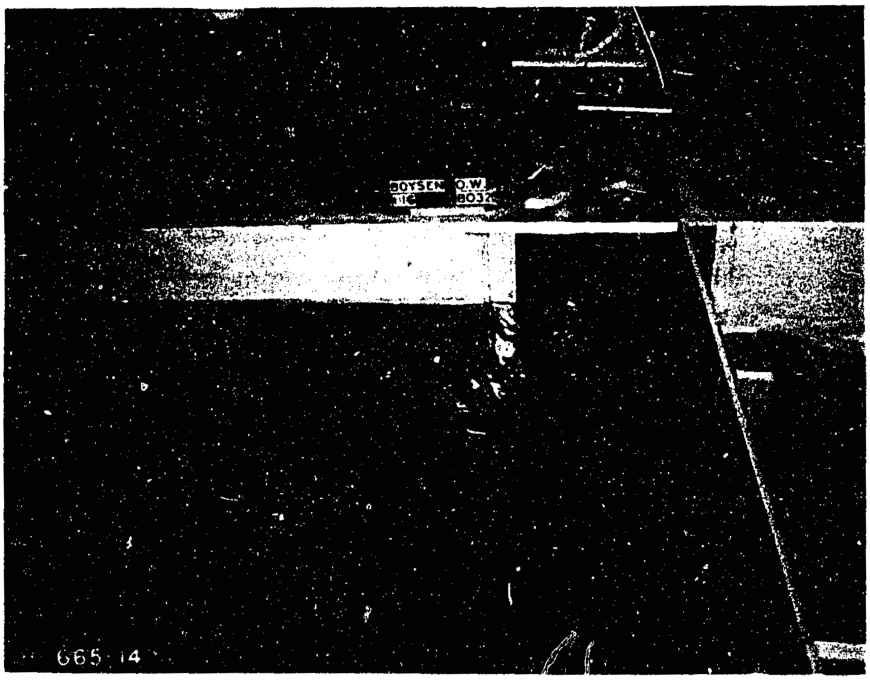
STUDY NO. 4 - RECOMMENDED DESIGN

1:16 MODEL BOYSEN OUTLETS

FIGURE 19



A. Both valves fully open, discharge 1320 second-feet. Tailwater elevation 4616



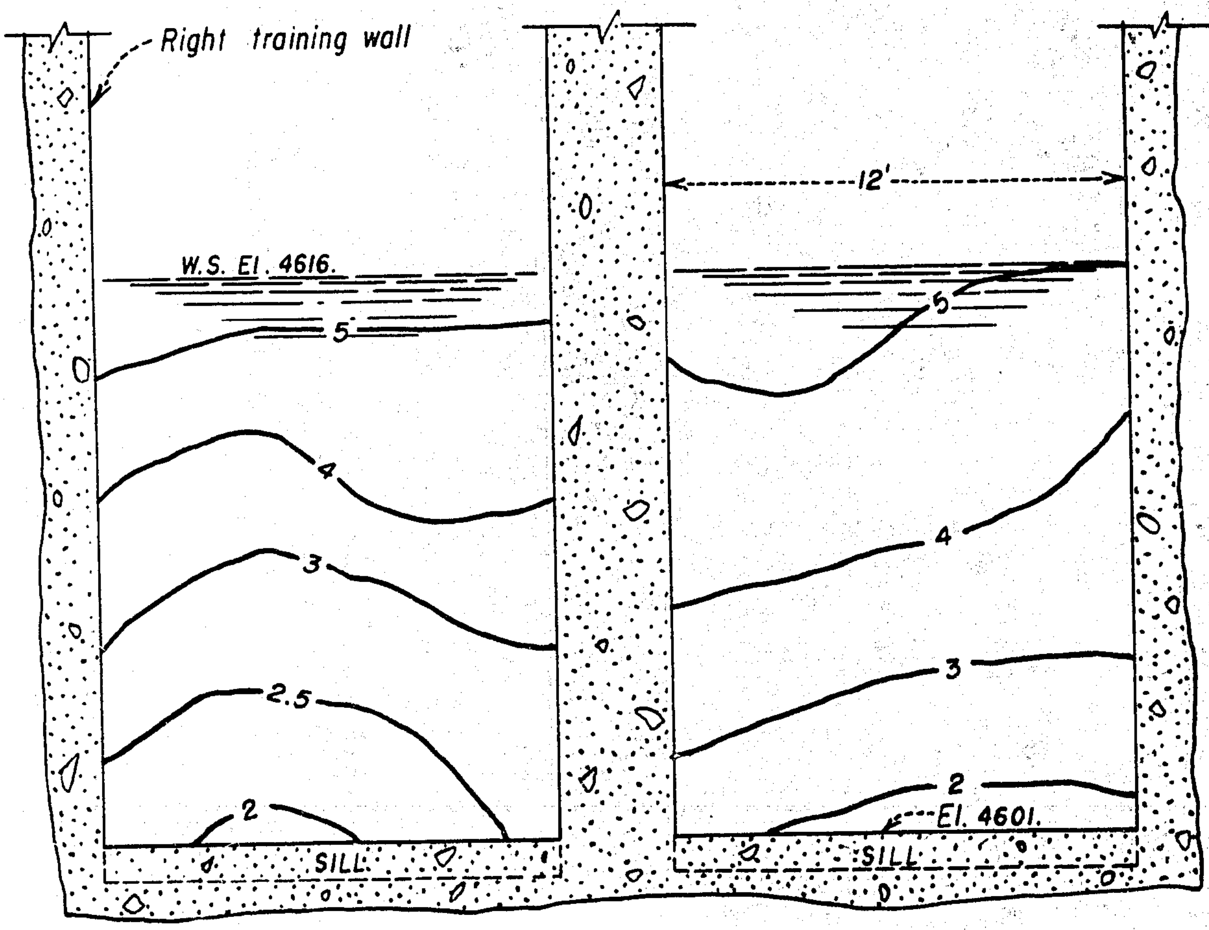
B. Both valves 50 percent open, discharge 660 second-feet. Tailwater elevation 4616

STUDY NO. 4 - RECOMMENDED DESIGN

1:16 MODEL BOYSEN OUTLETS

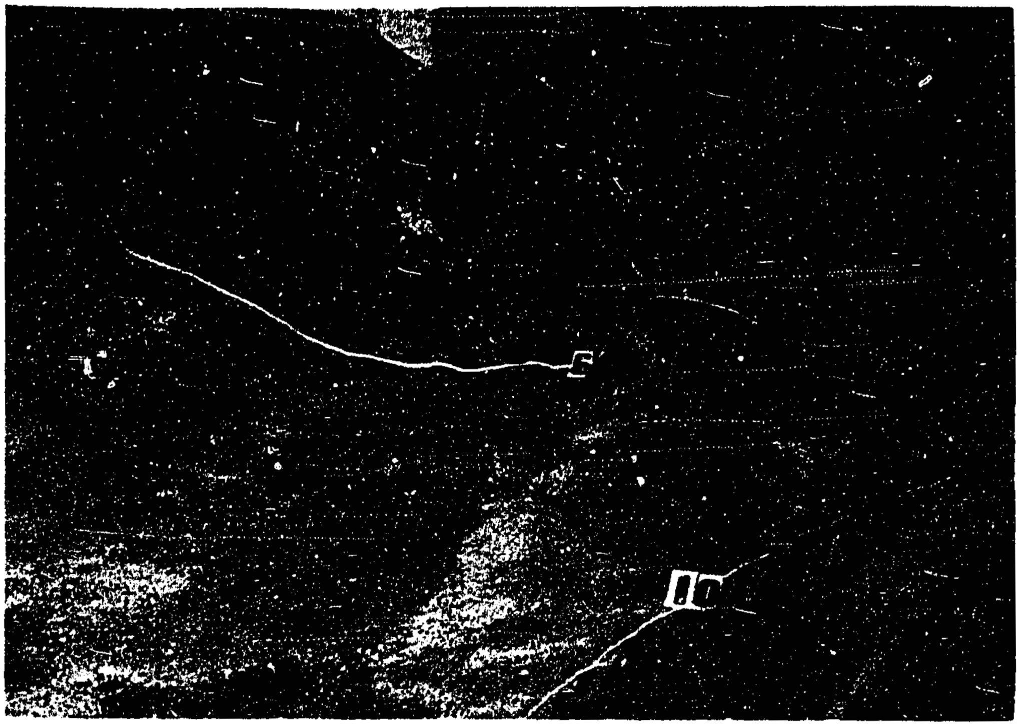
NOTE

Reservoir W.S. Elevation 4725.
Total discharge from two valves 1320 second-feet.
Velocities in feet per second.

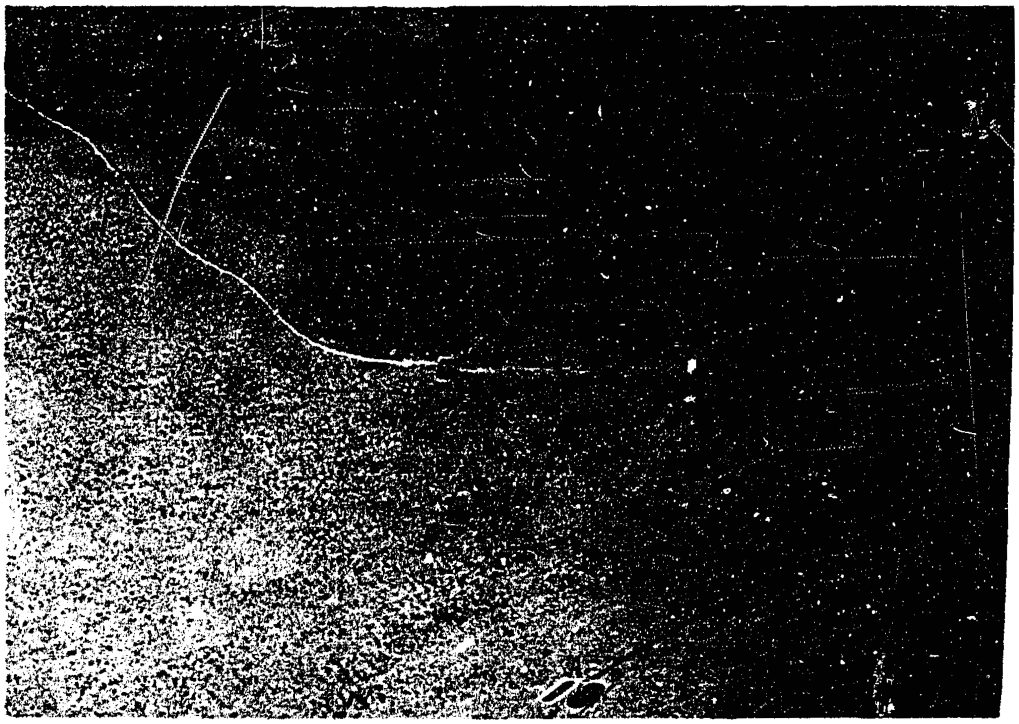


VELOCITY DISTRIBUTION AT DOWNSTREAM END OF STILLING BASIN

BOYSEN OUTLET WORKS
RECOMMENDED DESIGN
STUDY NO. 4



A. Without end sill



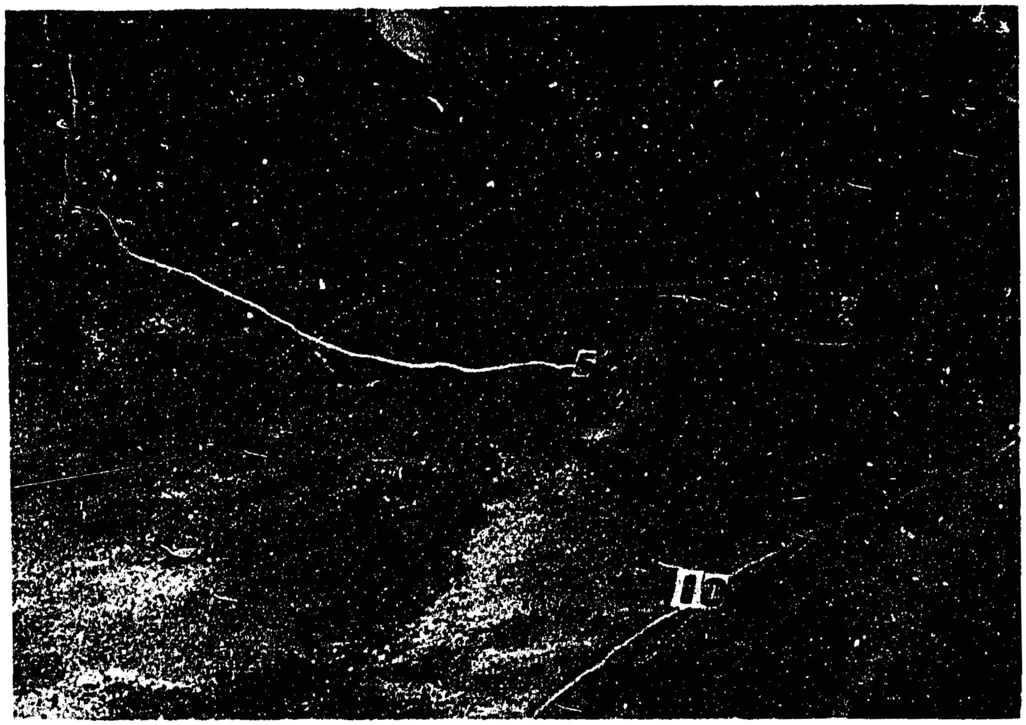
B. With 1 foot end sill

Scour after 1 hr. discharge from both valves of
1320 sec.-ft. tailwater elevation 4616

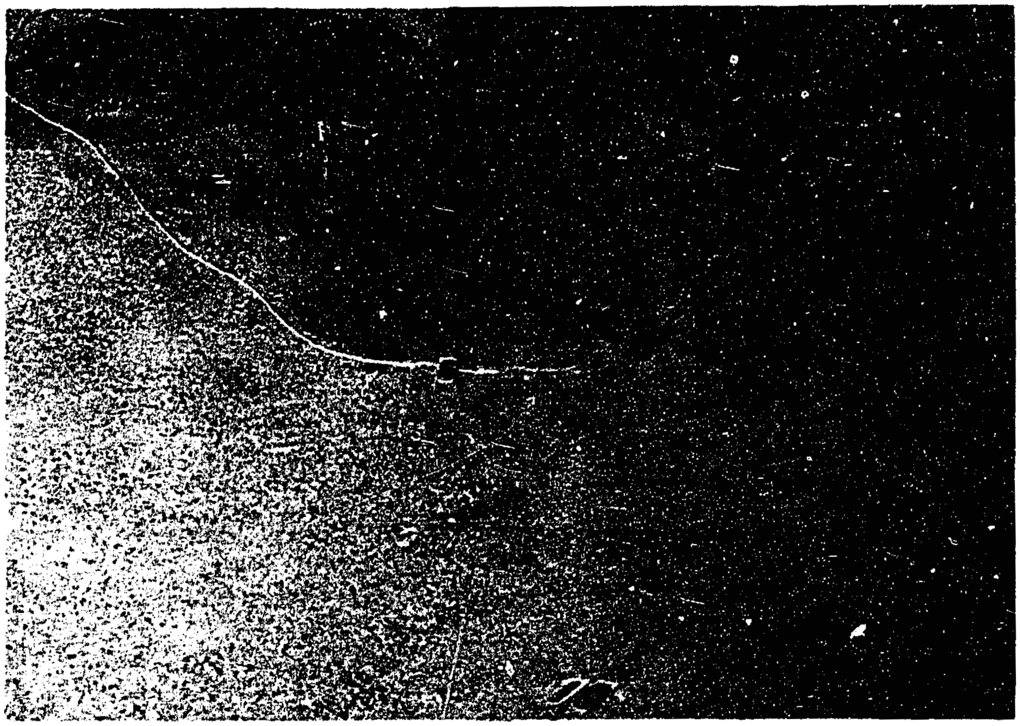
STUDY NO. 4 - RECOMMENDED DESIGN

1:16 MODEL BOYSEN OUTLETS

FIGURE 21



A. Without end sill



B. With 1 foot end sill

Scour after 1 hr. discharge from both valves of 1320 sec.-ft. tailwater elevation 4616

STUDY NO. 4 - RECOMMENDED DESIGN

1:16 MODEL BOYSEN OUTLETS